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# A DIGITAL AUDIO LINK TO THE CHANNEL ISLANDS IN THE UHF TELEVISION BAND:

## Protection of television signals from digitally modulated interference

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# A DIGITAL AUDIO LINK TO THE CHANNEL ISLANDS IN THE UHF TELEVISION BAND: PROTECTION OF TELEVISION SIGNALS FROM DIGITALLY MODULATED INTERFERENCE

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**Summary**

*Proposals have been made to use a digitally modulated signal in a UHF television channel to feed radio programme sound to the Channel Islands. It is clearly necessary to demonstrate that the proposed link will not cause unacceptable interference to existing UHF television services, including those of France. However, calculations concerning the problem have been hindered because the protection ratio needed when an interferer is digitally modulated was not known; in contrast, values for continuous wave (CW) or television interferers are provided by the CCIR and are well established.*

*Subjective tests were therefore conducted to establish the protection ratios for SECAM and PAL television signals suffering interference of the type produced by the proposed digital link. The results confirm that the energy dispersal provided by digital modulation of an interfering signal reduces the visibility of worst case interference so that the protection ratio can be relaxed accordingly, by an amount ranging from 3 to 12 dB for SECAM and 2 to 10 dB for PAL. If 'precision offset' of the carrier is used the visibility of CW interference is greatly reduced whereas the visibility of digitally modulated interference is unchanged; the protection ratio for digitally modulated interference is therefore the same with and without 'precision offset'.*

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# A DIGITAL AUDIO LINK TO THE CHANNEL ISLANDS IN THE UHF TELEVISION BAND: PROTECTION OF TELEVISION SIGNALS FROM DIGITALLY MODULATED INTERFERENCE

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## 1. INTRODUCTION

At present, the Band II VHF/FM transmitter at Les Platons on the Channel Islands obtains its sound-programme feeds using diversity reception of signals from transmitters at Rowridge and North Hessary Tor. Diversity reception is necessary because neither signal on its own would provide a service of adequate quality and reliability. However, in order to comply with an international agreement[1], the Rowridge transmitter will be modified so that less power is radiated towards France, with the unfortunate result that the Rowridge signal will no longer be adequate to play its part in the diversity system feeding the Channel Island transmitter. An alternative link will thus become necessary.

A digital link has been proposed as the replacement for the diversity system. It would operate from Stockland Hill UHF station using relatively low power (250 W e.r.p.) at a frequency within UHF Channel 30. Digital data would be carried in NICAM format[2] at 2.048 Mbit/s, using Tamed Frequency Modulation (TFM)[3].

The extent (if any) to which this link might interfere with any existing or planned UHF services must be assessed; this problem is addressed in Ref. 4. However, the calculations of Ref. 4 could not at first be made because the required protection ratio between wanted and interfering transmissions was not known for the case in question, where the wanted signal is a television signal and the interferer is digitally modulated. The protection ratio is tabulated by the CCIR for the cases of television or continuous wave (CW) signals interfering with television, but the energy dispersal produced by digital modulation was expected to permit a relaxation of the protection ratio from the value for CW interference. A 3 dB relaxation was tentatively assumed for initial estimates.

This Report describes experiments performed to establish the necessary protection ratios when a digitally modulated signal of the type proposed interferes with a television signal of either L/SECAM (French) or I/PAL (UK) standard.

## 2. EXISTING PLANNING STANDARDS

The protection ratios required when CW or television signals interfere with a wanted television signal are specified in CCIR Recommendation 655[5]. This Recommendation was recently published, superseding Report 306 which had previously been used to guide international planning. The experimental work described here took place before the publication of Rec. 655, nonetheless the results will be discussed in relation to Rec. 655 as far as possible.

The protection ratio is defined as the ratio of the wanted signal level to the interfering signal level — the carrier-to-interference ratio (C/I) — which must be equalled or exceeded in order to guarantee a particular standard of service. For this purpose the level of the vision signal is defined as the r.m.s. value of the carrier at peaks of the modulation envelope (taking no account of the chrominance signal in positive modulation systems). Thus for System L/SECAM (positive modulation) we take the r.m.s. carrier level corresponding to peak white, and for System I/PAL (negative modulation) that level corresponding to peak syncs. The level of a CW interferer is simply its r.m.s. value. Note that the protection ratio as defined applies to RF signals.

The severity of the impairment caused by an interfering signal depends not only upon its relative level but also its frequency, conveniently expressed in terms of the frequency offset of the interferer with respect to the carrier frequency of the wanted vision signal. To a first approximation the effect is worst when the offset is near zero, corresponding to low beat frequencies, with another peak for offsets in the region of the colour subcarrier frequency. At high and low frequency extremes the effects of IF filtering (which includes a vestigial sideband (VSB) characteristic) come into play.

In addition to this coarse variation with offset there is also fine variation. For example, consider a low offset frequency, e.g. around 1 MHz. If this offset were fine-tuned to be an exact multiple of line-scanning frequency the interference caused by a CW signal would take the form of stationary coarse vertical bars. If very slightly de-tuned the bar pattern would move, while with further de-tuning stationary or moving patterns of an increasingly fine and sloping character would result. Of all these patterns (all resulting from about the same offset frequency, as measured on a coarse scale) the most visible is the stationary or nearly stationary coarse pattern of vertical bars and Recommendation 655 accordingly specifies protection ratios for three operating conditions: 'non-controlled'; 'non-precision offset', where the

frequency offset is maintained within a tolerance of ± 500 Hz; and 'precision offset', where the frequency offset is controlled accurately enough (each carrier accurate to ± 1 Hz) and is also carefully related to the field frequency.

Rec. 655 specifies different protection ratios for continuous interference and for interference which only occurs occasionally, such as tropospheric interference.

## 3. THE SUBJECTIVE TESTS

### 3.1 The cases to be examined

Ref. 4 proposes the transmission of one or two carriers, each modulated by a 2.048 Mbit/s signal, within Channel 30. Preliminary study of the problem of interference to the digital signals resulting from a television signal suggested the following choice of frequencies: if only one digital carrier is used, its offset should be about +3.4 MHz from the television carrier, whereas if two digital signals are radiated then their offsets should be about +2.4 MHz and +4.4 MHz.

The three offset values +2.4, +3.4 and +4.4 MHz are thus of interest. Because these are well within the channel, and clear of the effects of VSB filtering, it is possible to study the problem at baseband, simplifying the experimental arrangement.

It is not intended that any special control should be applied to the frequency (or frequencies) of the proposed digital link, thus the case of most interest is the 'non-controlled condition' of Rec. 655. Furthermore, it would not be expected that any benefit would be gained if the carrier frequency of this relatively wideband digital link were carefully controlled. The case of 'precision offset' was included in the experiments in order to confirm this.

Since the protection ratios for CW interference specified by the CCIR are well established for use in international frequency planning it was thought best to devise an experiment to establish the extent to which digital modulation changed the protection ratio required. This would avoid uncertainty about consistency in the assessment of absolute degrees of impairment. Thus subjects were asked to choose the level of digital interference which caused a subjectively equivalent degree of impairment to that caused by reference levels of CW interference. For each combination of interfering frequency and colour system, two CW levels were chosen which roughly corresponded to the levels acceptable for tropospheric and continuous interference. Obviously, since a comparison method was being used, the lower levels of CW interference had to be chosen so that some effect at least was visible otherwise a subjectively equivalent level of digital interference could not possibly be determined.

The levels of interference, expressed as carrier-to-interference ratios, and offset frequencies are summarised in Tables 1 and 2. The reasons for the choice of these specific frequencies are outlined in Appendix 1.

*Table 1: SECAM Test Conditions*

| Offset frequency, MHz | C/I ratio, dB, for CW interference | |
|---|---|---|
| | Low level | High level |
| 'Non-controlled' | | |
| 2.40625 | 51 | 38 |
| 3.40625 | 48 | 38 |
| 4.396101 | 47 | 43 |
| 'Precision offset' | | |
| 2.401025 | 36 | 28 |
| 3.401025 | 38 | 28 |
| 4.406248 | 38 | 33 |

*Table 2: PAL Test Conditions*

| Offset frequency, MHz | C/I ratio, dB, for CW interference | |
|---|---|---|
| | Low level | High level |
| 'Non-controlled' | | |
| 2.40625 | 47 | 37 |
| 3.40625 | 47 | 37 |
| 4.396101 | 50 | 42 |
| 'Precision offset' | | |
| 2.401025 | 33 | 25 |
| 3.401025 | 39 | 31 |
| 4.3997375 | 35 | 31 |

### 3.2 Experimental arrangement

The experimental arrangement is shown in Fig. 1.

As mentioned in Section 3.1, the range of interfering frequencies is such that the experiment can be conducted simply at baseband frequencies. SECAM or PAL signals from a high-quality slide scanner were fed to a monitor equipped with decoders for SECAM and PAL via distribution amplifiers and a summing pad where the interfering signal was added.

The source for digitally modulated interference was a TFM (tamed frequency modulation) modulator*

* Manufactured to a BBC design.

fed with a pseudo-random binary data sequence. The TFM modulator has a crystal-controlled carrier frequency of about 7.5 MHz. This was translated to the precise baseband frequency required (in the range 2.4 to 4.4 MHz) using a mixer with high-side injection from a frequency synthesiser.

In order to ensure that CW and TFM interferers had the same frequency, the TFM modulator was modified so that the modulation could be switched off to provide CW. The same switch also controlled a relay which switched between two attenuators, A and B.

Careful attention was necessary in setting the signal levels in the experiment, especially since the definition of protection ratio relates to RF vision-signal levels, whose relationship to baseband levels depends on the television standard in use. Level calibration was performed as follows:

> With the modulation turned off, levels were adjusted so that with attenuator A set to 'zero' the sinewave baseband interference had the same peak-to-peak value (0.7 V) as the video black-to-white level. The desired level of CW interference could then be set for any test condition by adjusting attenuator A. The corresponding carrier-to-interference ratio in dB is therefore the attenuator setting plus a correction factor, derived in Appendix 2, accounting for the way in which protection ratio (and hence C/I measurement) is defined at RF. Attenuator B, for TFM, comprised two attenuators, one variable, for use by the observers (see Section 3.3 below) and another, pre-set, used only during calibration. TFM calibration was performed after that for the CW signal by adjusting the pre-set attenuator so that CW and TFM interferers had the same power when the 'user' attenuators were set to the same value. The same correction factor would then apply to determine the TFM carrier-to-interference ratio from its 'user' attenuator.

### 3.3 Conduct of the tests

The form of the tests, whereby each observer participated in adjusting the level of interference, dictated that only one subject could take part at a time. With the time available it was only possible to use four expert observers for each series of tests.

Each observer attended four sessions: one for each of the combinations of SECAM or PAL with two test pictures (Test Card F and the EBU slide 'Formal Pond'). These particular test pictures were chosen as being most likely to be sensitive to the type of impairment being considered. During a session the twelve test conditions (six frequencies at two levels) were presented in random order, with each condition occurring twice. For each test condition the observer was asked to grade the impairment caused by the given level of CW interference, and then to adjust the level of digitally modulated interference to give the same degree of picture impairment. The observer was free to operate the switch, selecting CW or digital

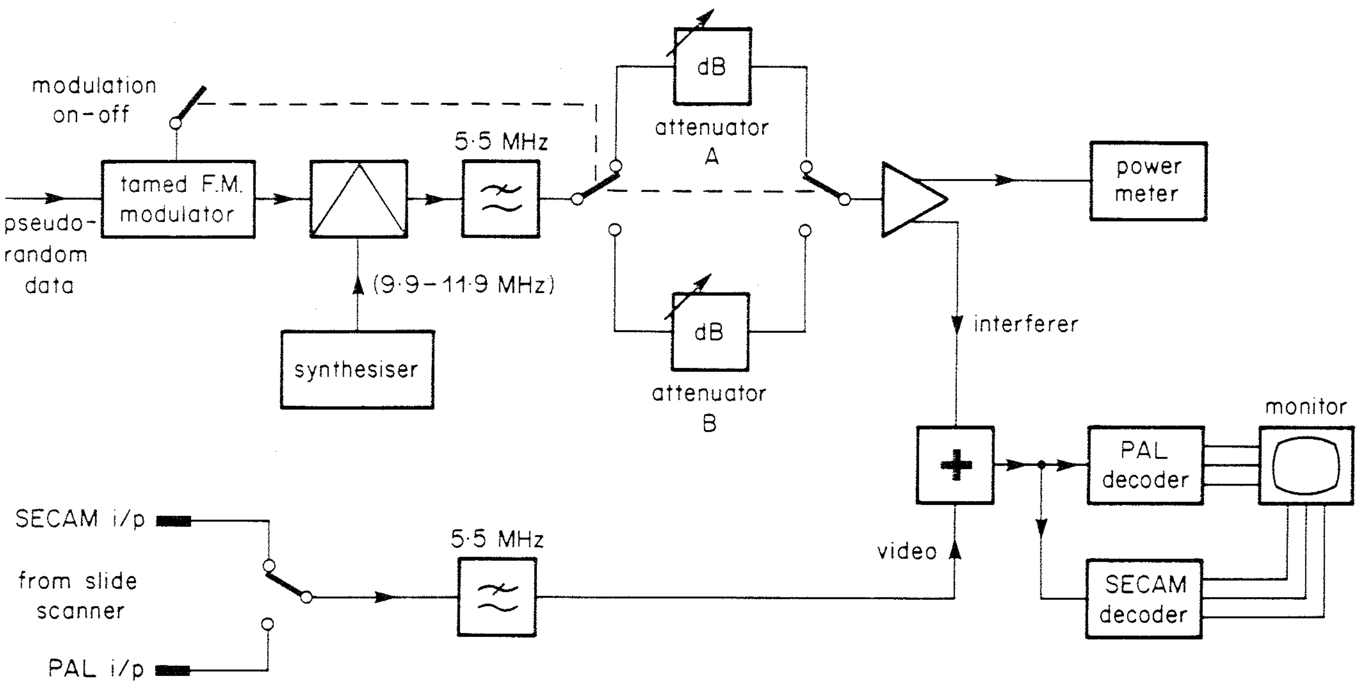


*Fig. 1 - The experimental arrangement for the tests.*

interference at will, and to adjust the digital interference level, as often as desired until satisfied that the impairments were equivalent. Impairments were graded using the CCIR 5-point impairment scale, shown in Table 3.

*Table 3: The CCIR 5-point Impairment Scale*

| Grade | Impairment |
|---|---|
| 5 | Imperceptible |
| 4 | Perceptible but not annoying |
| 3 | Slightly annoying |
| 2 | Annoying |
| 1 | Very annoying |

## 4. RESULTS

### 4.1 SECAM: non-controlled frequency offset

The results are summarised in the bar chart of Fig. 2. There are six test conditions corresponding to the combination of three frequency offsets with two levels of interference. The carrier-to-interference ratio corresponding to the level of CW interference imposed by the experimenter for each condition is shown as the hatched, right-hand bar of each pair in the upper part of the figure. The open bar on the immediate left of each of the hatched bars shows the C/I ratio for digital modulation which the subjects assessed to cause the *same* degree of impairment as the imposed CW interference. This degree of impairment was also assessed and is indicated by the descending bar (in the lower part of the figure) for each test condition; the highest CCIR grade (least impairment) has the longest descending bar.

The results shown are the average of the results for all observers and the two test slides. There was no significant difference between the results from the two test slides, while the consistency of observers between the two presentations of each test condition was excellent. The correlation between observers was generally good.

It can clearly be seen that for every test condition a lower protection ratio is required for the digitally modulated signal than for CW interference. The advantage is greatest for the 2.4 MHz offset and least for 4.4 MHz; it is also greater for low levels of interference rather than high. In the worst case (4.4 MHz offset, high level of interference) the advantage is 3 dB. For the best case (2.4 MHz offset, low level of interference) the advantage is 12 dB.

The purpose of the tests was to determine the extent to which the protection ratio required for digital modulation differed from that for CW, rather than to determine absolute values. Nevertheless a comparison is of interest. Rec. 655 states that the values given for tropospheric interference (i.e. occasional in occurrence) correspond to a 'slightly annoying' impairment. Presumably this means Grade 3 on the CCIR impairment scale. The protection ratios given by Rec. 655 for CW interference to system L/SECAM television are given in Table 4.

*Table 4: Protection Ratios for CW Interference to L/SECAM Television Signals, according to CCIR Rec. 655*

| Non-controlled frequency offset | CW protection ratio, dB | |
|---|---|---|
| | Tropospheric interference | Continuous interference |
| 2.4 MHz | 39 | 48 |
| 3.4 MHz | 37 | 43 |
| 4.4 MHz | 38 | 43 |

At 2.4 MHz, the CCIR CW 'tropospheric' protection ratio value of 39 dB lies close to our 'high' condition, for which an impairment grading slightly worse than Grade 2 (Annoying) was achieved. Our 'low' condition has the CW C/I ratio value of 51 dB which exceeds the CCIR 'continuous' protection ratio by 3 dB, yet still only attracts a grading little better than Grade 3 (Slightly annoying). Thus for 2.4 MHz our results suggest that the CCIR protection ratio values are perhaps not stringent enough; nevertheless, a great advantage (7 to 12 dB) is indicated for digital modulation.

At 3.4 MHz and 4.4 MHz our results show better agreement with CCIR values.

Thus the validity of the assumption made in Ref. 4 that a digitally modulated signal causes less interference than CW is confirmed. Digital modulation having the parameters used in the tests requires a protection ratio which is less than that required for CW by at least 3 dB. The 3 dB advantage applies at 4.4 MHz offset; the advantage is still greater at the lower frequencies.

### 4.2 SECAM: precision offset

Precision offset is the technique used to reduce the visibility of CW or, more usually, television interference to a wanted television signal by very careful control of the frequency offset between them. Thus use of precision offset reduces the protection ratio required for CW signals. This is confirmed by the test results shown in Fig. 3, where the format is the same as previously described for Fig. 2. Comparing the two figures we can observe that lower

CW protection ratios are needed when precision offset is used. Note that when comparing test conditions it is necessary to compare those having like impairment grading. The precision-offset frequencies used in the experiments were chosen according to the then current, but now superseded, CCIR Report 306. Detailed consideration of the CW protection ratios for the precision-offset case is not therefore worthwhile; it was not in any case the aim of this work.

The digitally modulated signal is dispersed over a wide bandwidth and so the precise value of its nominal centre frequency is of little consequence. This is confirmed when comparing Figs. 2 and 3, again taking care to compare like with like. The effect of this is to turn the advantage of digital modulation over CW, for the case of non-controlled frequency offset, into a disadvantage when precision offset is applied.

Precision offset is thus a useful technique for reducing the effects of CW interference; it is of no value for relatively wideband digitally modulated interferers, as confirmed in these tests.

### 4.3 PAL: non-controlled condition

The protection ratios specified by Rec. 655 are given in Table 5. The results obtained in the experiment are shown in Fig. 4, using the same format as before. Once again a clear advantage is shown for the digitally modulated interferer. In the worst case (3.4 MHz, high level interference) the advantage is only 2 dB but for all other test conditions it is much greater, in the range 5.5 to 10 dB.

*Table 5: Protection Ratios for CW Interference to I/PAL Television Signals, according to CCIR Rec. 655*

| Non-controlled frequency offset | CW protection ratio, dB | |
|---|---|---|
| | Tropospheric interference | Continuous interference |
| 2.4 MHz | 41 | 50 |
| 3.4 MHz | 43 | 50 |
| 4.4 MHz | 45 | 53 |

### 4.4 PAL: precision offset

The results obtained are shown in Fig. 5, using the same format as before. As for SECAM, the CW protection ratios are relaxed with precision offset (although the change is less marked at 3.4 MHz) while the digital protection ratios are not, so that the significant advantage of digital modulation when the offset is non-controlled is turned to a disadvantage with precision offset.

### 4.5 Summary of Results

Protection ratios against digital interference of the type under consideration can be deduced by applying the relaxations obtained in Sections 4.1 and 4.3 to the CW protection ratios specified by Rec. 655 (and reproduced in Tables 4 and 5). The results are presented in Table 6. A range of protection ratios is quoted because the relaxation depends on the interference level.

*Table 6: Summary of the Experimental Results*

| System of wanted signal | Non-controlled frequency offset, Mz | Permissible protection ratio relaxation, dB | Protection ratios, dB | | | |
|---|---|---|---|---|---|---|
| | | | Tropospheric interference | | Continuous interference | |
| | | | CW (CCIR Rec. 655) | Digital modulation | CW (CCIR Rec. 655) | Digital modulation |
| L/SECAM | 2.4 | 7 - 12 | 39 | 27 - 32 | 48 | 36 - 41 |
| | 3.4 | 4 - 7 | 37 | 30 - 33 | 43 | 36 - 39 |
| | 4.4 | 3 | 38 | 35 | 43 | 40 |
| I/PAL | 2.4 | 6 - 10 | 41 | 31 - 35 | 50 | 40 - 44 |
| | 3.4 | 2 - 6 | 43 | 37 - 41 | 50 | 44 - 48 |
| | 4.4 | 6 - 9 | 45 | 36 - 39 | 53 | 44 - 47 |

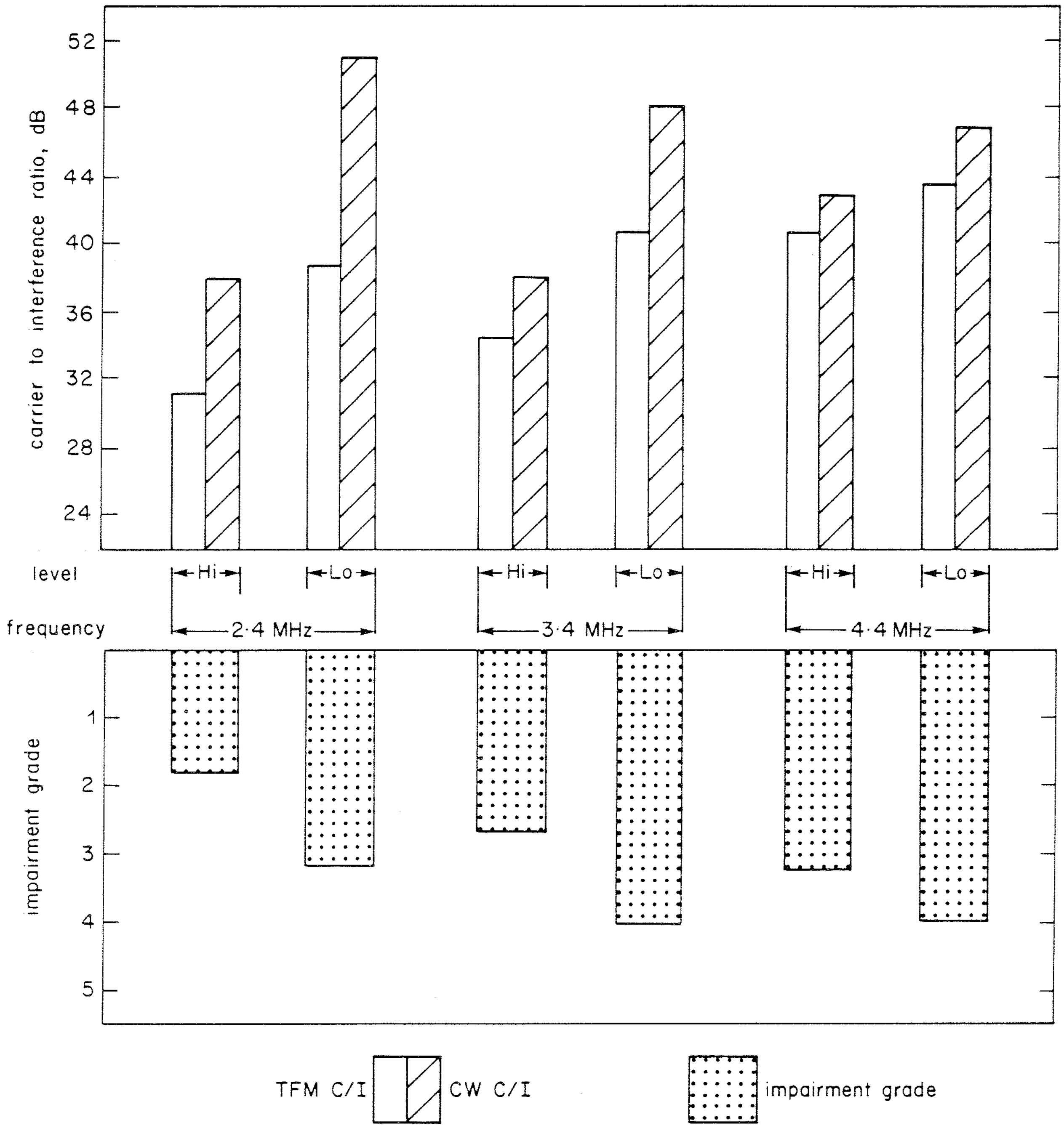


*Fig. 2 - Results for SECAM: non-controlled offset.*

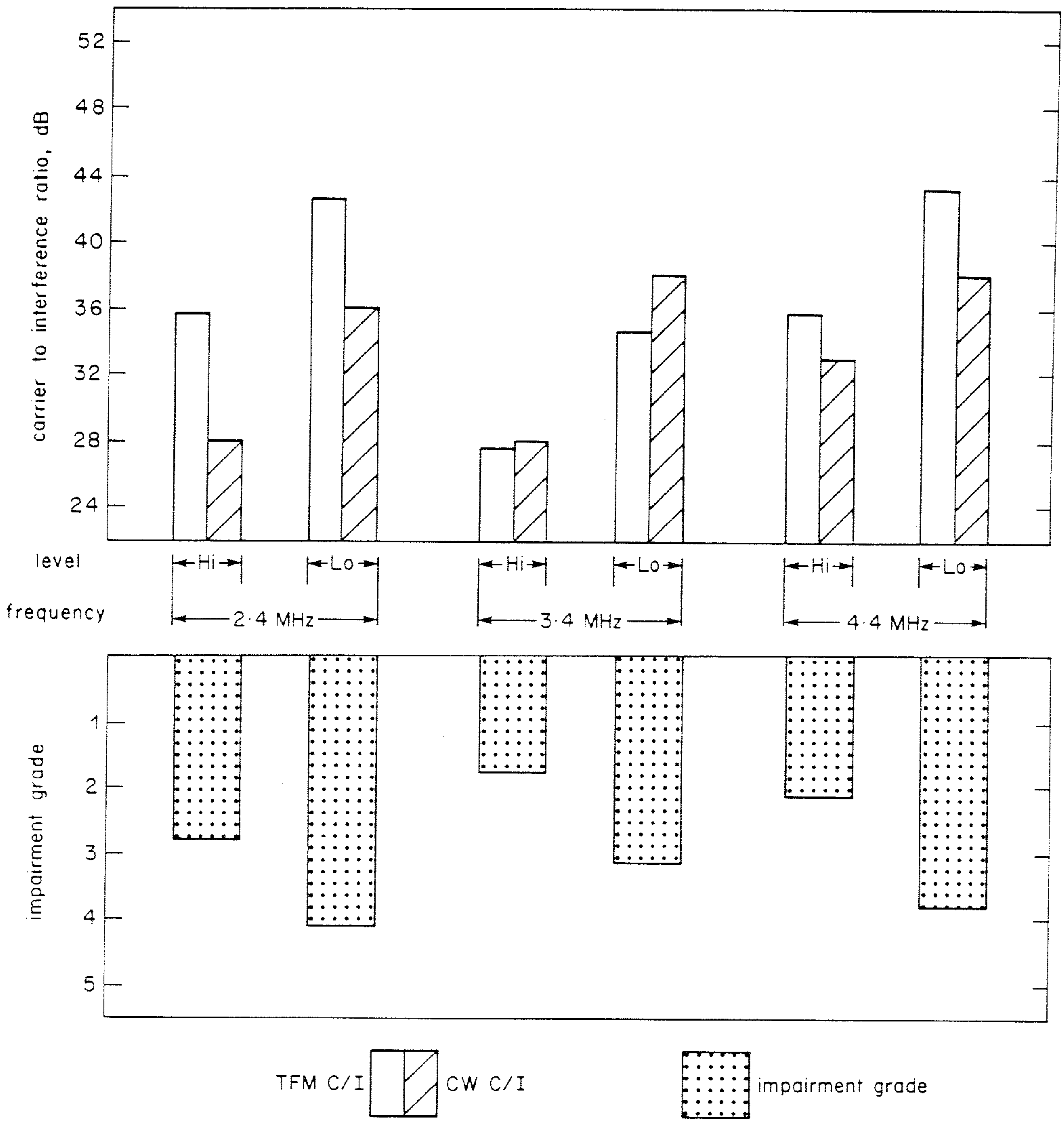


*Fig. 3 - Results for SECAM: precision offset.*

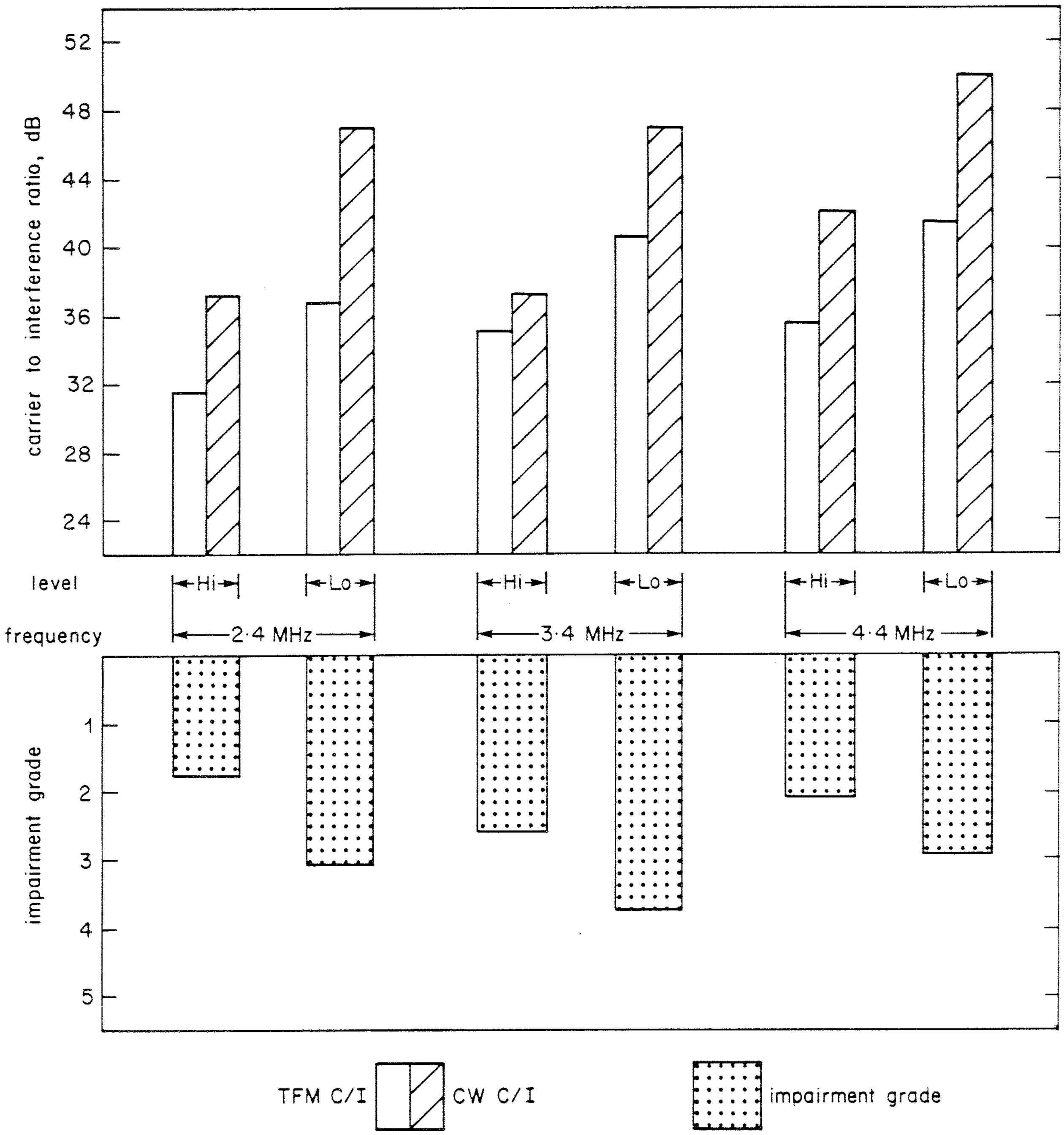


*Fig. 4 - Results for PAL: non-controlled offset.*

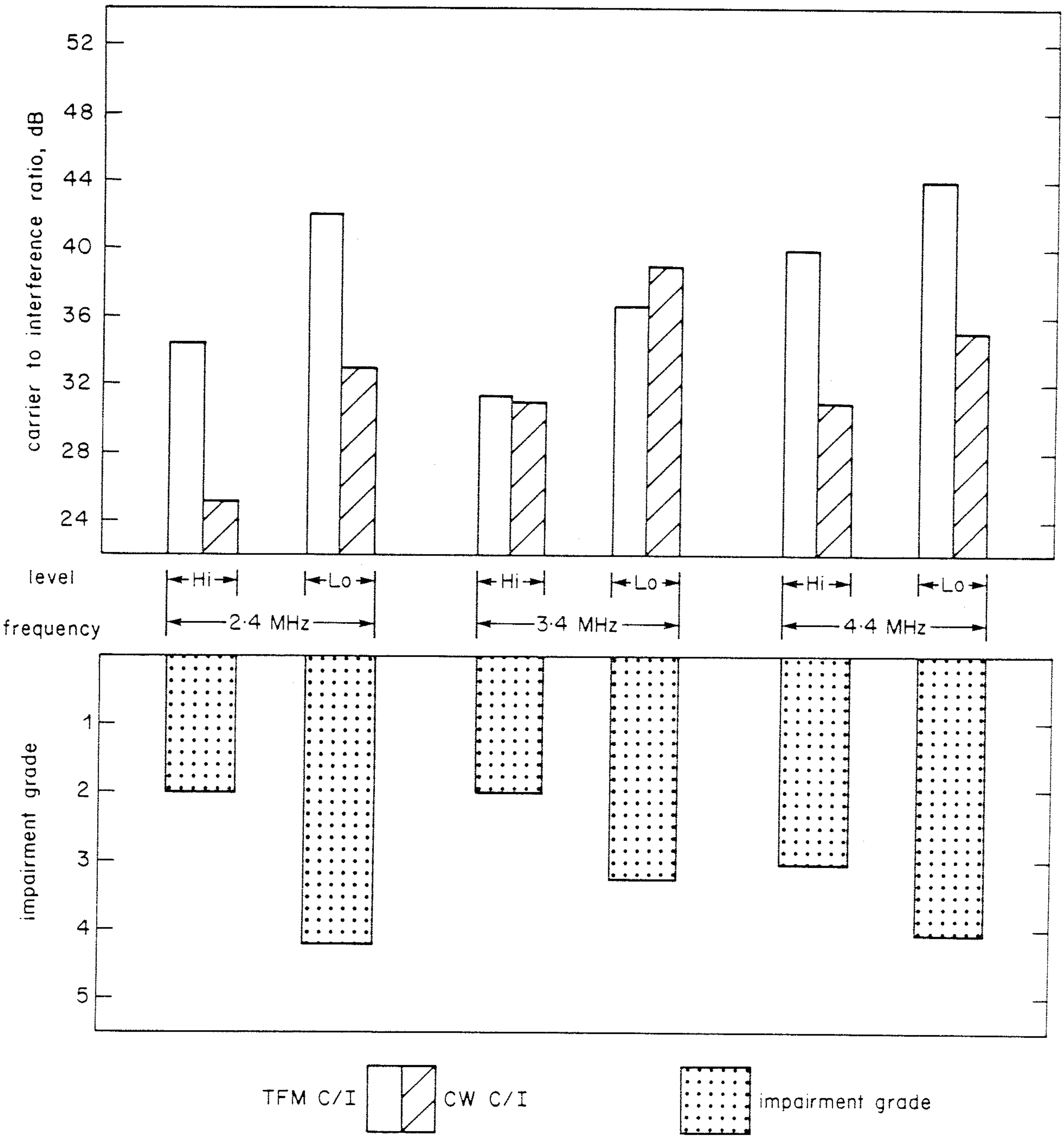


*Fig. 5 - Results for PAL: precision offset.*

## 5. CONCLUSIONS

Subjective tests have been carried out to compare the impairments resulting when a vision signal suffers interference from either a CW source or one carrying a 2 Mbit/s signal using tamed frequency modulation.

The tests have shown that, for a given carrier-to-interference ratio, the interference from the digitally modulated signal is less objectionable than that from a CW carrier, in the case when no special care is taken to regulate the carrier frequencies precisely, (the so-called 'non-controlled' condition). The appropriate protection ratios against interference from the digitally modulated signal are therefore less than those for CW interferers, by an amount which depends on the frequency offset and the television standard. For SECAM-coded signals the reduction for the range of offsets tested is a minimum of 3 dB, extending to as much as 12 dB in the best case examined. For PAL-coded signals, the reduction similarly ranges from 2 to 10 dB. The resulting protection ratios are given in Table 6.

When 'precision offset' is applied to a CW interferer the visibility of the interference pattern it causes is greatly reduced. No such reduction applies when the interferer is digitally modulated; the precise value of carrier frequency of such a widely dispersed signal is of little consequence. There is therefore no requirement for very precise frequency control of the digitally modulated signal.

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## APPENDIX 1

### Choice of carrier offset frequencies for the experiment

The precise values of carrier offset frequencies for the interfering signal were chosen as follows. For the 'non-controlled' condition we must choose those values of offset, near the nominal ones of 2.4, 3.4 and 4.4 MHz, which cause the most visible and objectionable patterning, so that we may be certain of establishing a worst-case result. In the luminance band, whether in the SECAM or PAL systems, this occurs when the offset frequency is at or very near to an exact multiple of line frequency, so that coarse vertical bars are produced which are stationary or very slowly moving. Thus for nominal 2.4 and 3.4 MHz offsets we choose the nearest multiples of line frequency, namely 154 $f_L$ (2.40625 MHz) and 218 $f_L$ (3.40625 MHz). In the chrominance band, a frequency differing from a line-frequency multiple by about $\frac{1}{3} f_L$ and equal (or very close) to a multiple of picture frequency seems to be most objectionable. The frequency 4.396101 MHz was chosen for both SECAM and PAL. It is roughly 281 $\frac{1}{3} f_L$.

The 'precision-offset' frequencies for SECAM and PAL in the luminance band are defined differently in Report 306*. However, when the nearest multiple of line frequency is an even one — as is the case for both our frequencies (2.4 MHz and 3.4 MHz) — the result is the same, namely 2.401025 and 3.401025 MHz. Strictly the definition of 'luminance band' for SECAM in Report 306 does not extend to 3.4 MHz (it is in an undefined region between luminance and chrominance) but preliminary tests showed that the 'luminance' definition of precision offset was more satisfactory than the 'chrominance' one.

For 4.4 MHz, clearly within the chrominance band, application of the Report 306 formulae for precision offset leads to the choice of 4.406248 MHz† for SECAM and 4.3997375 MHz for PAL.

* Now superseded by Recommendation 655, but current at the time of the tests.

† The 2 Hz departure from the nominal calculated value is permissible within the specified tolerances and was used for the tests to ensure a worst-case result for plain carrier interference, as preliminary tests suggested a marked increase in visibility.

## APPENDIX 2

### Derivation of correction factors when the carrier-to-interference ratio is measured at baseband

The protection ratio is defined as the necessary ratio between the powers of the vision RF signal and the interfering signal, where the power of the vision signal is that occurring at the peak of the modulation (neglecting chrominance). This 100% vision carrier amplitude corresponds to sync level for negative modulation, such as I/PAL, or white level for positive modulation such as L/SECAM. With this definition the levels of Table 7 apply.

*Table 7: Carrier Levels Corresponding to Significant Video Levels*

| | Nominal carrier amplitudes, % | |
|---|---|---|
| | I/PAL | L/SECAM |
| Black level | 76 | 30 |
| White level | 20 | 100 |

Suppose a picture signal is transmitted containing a sinusoidal variation from black to white, at a frequency within the video band but high enough not to be transmitted within the vestigial sideband. For L/SECAM this sinusoid varies from 30% to 100% carrier amplitude, i.e. 65% ± 35%. This corresponds to a 'carrier' of 65% vision-carrier amplitude, plus two sidebands each of 17½% amplitude. At this modulating frequency only the upper

sideband and the carrier are radiated. From these the receiver produces the desired black-to-white sinewave. The power of the upper sideband (during the active period) is 20 $\log_{10}$ (0.175) which equals − 15.1 dB with respect to the defined vision carrier power. An interfering signal of the same frequency and relative level would also produce a black-to-white sinewave. In the experimental arrangement the CW interference attenuator was arranged to read 'zero' when the baseband interference was a 0.7 Vp-p sinewave; from the above this clearly corresponds to a C/I ratio of 15.1 dB. Thus the RF C/I ratio equals the attenuator setting plus 15.1 dB.

For I/PAL the reasoning is similar. In this case, a black-to-white sinusoid corresponds to an excursion of 20% to 76% vision carrier, i.e. 48% ±28%. The upper sideband is thus 14% of vision carrier, i.e. −17.1 dB with respect to the vision carrier. Thus for PAL the RF C/I ratio equals the attenuator setting plus 17.1 dB.



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